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# *Wheat Scab in Minnesota*

*By Jean MacInnes and Raymond Fogelman*
*Division of Plant Pathology and Botany*

UNIVERSITY FARM, ST. PAUL

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# WHEAT SCAB IN MINNESOTA

By Jean McInnes and Raymond Fogelman[1]

## INTRODUCTION

Scab or "head blight" of wheat has been known in Minnesota for more than twenty years. The disease seems to have attracted little attention, however, until about 1915 when it became sufficiently prevalent, especially on Marquis wheat, to attract the attention of growers, who sent to the experiment station a great many diseased heads of wheat with the comment that head blight was doing a great deal of damage. Practically every one of these farmers said that Marquis was more severely injured than other varieties. Whether the introduction of Marquis and its general use was responsible for the increasing amount of scab is not definitely known, but it is certain that the disease seems to have become more prevalent with the general adoption of Marquis.

Altho considerable work already had been done on the disease, many facts concerning its general characteristics were still unknown when the writers began their investigations. The conditions most favorable for its development, the plants attacked, the distribution in the state, the amount of damage caused by the disease, and especially the control measures were known only very imperfectly. For this reason work on these various phases of the problem was begun in 1915 and has been continued until the present time. The major part of the work was completed in 1920 and little has been done since.

## HISTORICAL SUMMARY

Smith (32) apparently first described wheat scab in England in 1884. He stated that the disease was caused by *Fusarium culmorum* and named it "wheat scab." In 1890 Kirchner (16) stated that a similar organism caused a disease of wheat, oats, barley, rye, and maize in Germany. Chester (5) seems to have been the first to call attention to the seriousness of wheat scab in the United States. In 1890 he mentioned the disease as having been serious in Delaware in that year. Arthur (2) mentioned the disease as being destructive in Indiana in 1891, and Miss Detmers (6) called attention to the disease in Ohio in the same year. Miss Detmers considered

[1] The work in this paper was done under the direction of Dr. E. C. Stakman, head of the section of plant pathology. The writers wish to express their appreciation of his advice and criticism.

the cause of the disease to be *Fusarium culmorum* (W. G. Sm.). Pammel (18) also noticed the disease in Iowa that year, and Buckhout (4) said that the disease was abundant in Pennsylvania in 1892. Bessey (3) stated that the disease was prevalent in Nebraska a few years later. Since the disease already seemed to be widespread in the early nineties, it is quite likely that it had been in the country for some time.

The early reports mention mainly the appearance of the disease on the heads of wheat, and Rostrup (23, 24, 25, 26) appears to have been the first to show definitely that the causal organism might live over in the seed and cause seedling infection. According to von Tubeuf (33), Rostrup also described a seedling blight of oats in Denmark in 1893 which was caused by an organism similar to that which causes wheat scab. Tubeuf also says that Frank found a field of rye near Kiel, in Germany, in which the heads were almost completly destroyed by scab. Selby (27, 28) called the conidial stage of the causal organism *Fusarium roseum* Link and the perfect stage *Gibberella saubinetii* (Mont.) Sacc. Selby and Manns (30) published the results of rather extensive investigations in 1909, and reported, as a result of cross-inoculation experiments, that the scab organism infected wheat, oats, barley, and rye. They considered that the different organisms previously described as causing scab probably were the same. They also demonstrated that the fungus persisted in the seed and might destroy young seedlings grown from the infected seeds. In addition they isolated pure cultures of the scab fungus from alfalfa plants that were dying in the field. Later, Selby (30) listed in his handbook on plant diseases the following hosts for the wheat scab pathogene: alfalfa, barley, clover, corn, emmer, oats, rye, speltz, and wheat. Appel and Wollenweber (1) found that *Fusarium culmorum* could rot potato tubers, and Lewis (17) identified a Fusarium which caused a rot of squash in storage as *F. culmorum*. E. C. Johnson (13) showed that a culture of *F. culmorum* which he isolated from wilted oats caused a decrease in the germination of wheat, oats, and barley seeds inoculated with it. Wollenweber (35), in 1914, stated that *F. culmorum* was a wound parasite of cereals and caused scab and seedling blight. He found that it could rot sweet potatoes and states that it also had been isolated from corn, oats, wheat, rye, barley, lupin, cotton, sweet potato, cucumber, squash, and other plants. Harter, Weimer, and Adams (8) also found that *F. culmorum* and *G. saubinetii* could rot sweet potatoes. Apparently, therefore, the organism was very prevalent in nature and was capable of attacking, at least to a limited extent, several host plants.

The wheat scab organism was considered to be particularly destructive only to wheat until comparatively recently, when it was shown that it is also a destructive parasite of corn. Pammel, King and Seal (19, 20) showed that *Fusarium sp.* causes corn root-rots and also attacks the stalk and the ears of the corn plant. Hoffer and Holbert (9, 10) also showed this to be true. Furthermore, they (10) observed that wheat following corn was likely to be more scabby than wheat following wheat. In the same year, Hoffer, Johnson and Atanasoff (11) reported that cultures of *G. saubinetii* isolated from corn roots and stalks produced typical wheat scab. They obtained similar results by inoculating both wheat and corn with cultures isolated from infected wheat plants. Holbert, Trost and Hoffer (12) observed that various systems of rotation affected the amount of scab in wheat very considerably. They found that wheat sown on land which had grown two successive crops of corn was more severely injured by scab than that grown on land which had grown wheat the previous year or than wheat which was grown on land following oats. Johnson, Dickson and Johann (15) found that *Gibberella saubinetii* apparently was the principal cause of the epidemic of scab of cereals in 1919, and Hoffer and Holbert (10) found that the same organism was responsible for a great deal of the root- and stalk-rot of corn.

## GEOGRAPHIC DISTRIBUTION AND ECONOMIC IMPORTANCE

Scab has been reported on cereals in England, France, Germany, and Denmark, altho it seems that the disease is not so important in those countries as it is in the United States where it now ranks as one of the very destructive diseases of wheat and corn.

The general distribution of the disease in North America is shown in Figure 1. It has been reported from practically all wheat growing regions of the United States east of the Rocky Mountains as well as from Utah and Oregon. In Canada it seems to be most prevalent in the maritime provinces, Nova Scotia, Quebec, Ontario, New Brunswick, and Prince Edward Island. In 1919 it was quite destructive in those provinces and also appeared in southern Manitoba and in Saskatchewan.[2]

In Minnesota, scab of wheat has been most prevalent in the southern, southwestern, and west central wheat growing counties. It occurs in the Red River Valley, but is seldom as destructive as in the southern part of the state. Whether this is because more corn is grown in the

[2] Data furnished by Professor W. P. Fraser, Dominion Laboratory of Plant Pathology, University of Saskatchewan, Saskatoon, Saskatchewan.

southern half of the state, or because of the difference in climatic conditions, is uncertain. However, it seems to be quite clear that the disease on wheat is much more prevalent and serious in the corn-growing regions of the state. On the other hand, the rainfall in the southeastern section may be as high as 40 inches, while in the vicinity of Crookston, in the Red River Valley, it averages only about 18 inches. It is probable that both these factors influence the distribution.

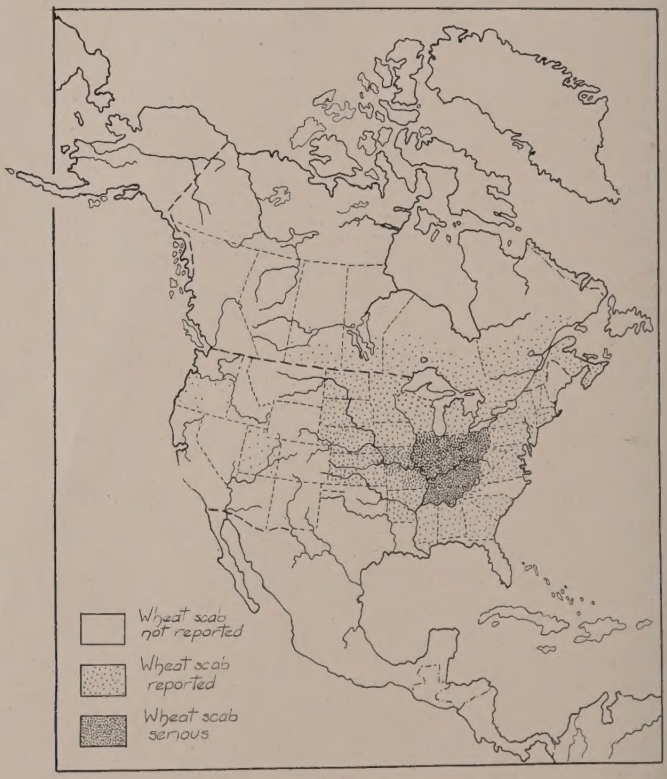


Fig. 1. Geographic Distribution of Wheat Scab in North America

The area where scab is reported serious corresponds closely with that of the production of soft red winter wheat in the United States.

The damage done by the wheat scab organism varies from year to year. In some years it becomes epidemic, while in others it does relatively little damage. For instance, there seem to have been severe attacks of scab in 1905 and 1907; and in 1915 it was destructive, the

total loss on wheat being estimated at 5 per cent. In 1916 there was considerable, but not so much as in 1915. The disease did little damage in 1917 and 1918. In 1919 and 1920 the yield of both spring and winter wheat in Minnesota, especially in the southern half of the state, was greatly reduced by scab. A similar epidemic occurred throughout the wheat growing regions of the United States in 1919 (14, 21, 22), about five per cent of the total crop having been destroyed.

The root-, stalk-, and ear-rots of corn caused by the scab organism appear to be less prevalent in Minnesota than in some of the states farther south and east. This may be because the development of the disease is influenced by temperature (34). Thus only occasional isolated fields seem to be seriously damaged in Minnesota, while the disease is often very serious in the more southern parts of the corn belt. In both 1919 and 1920 the estimated decrease in yield due to this disease was about four per cent of the total corn crop of the country (21, 22).

## SYMPTOMS OF SCAB ON WHEAT

Symptoms of scab on wheat are most conspicuous and characteristic on the heads. The disease may become evident soon after the heads have emerged from the sheath, altho it may not become apparent until much later. Affected spikelets often appear to have ripened prematurely, while healthy spikelets are still green. The glumes of the diseased spikelets, however, are usually pale and sickly, especially when they have been attacked while still young; and they may be partly covered with a varying amount of white or slightly pinkish mycelium. They are often cemented together by a smooth pinkish, orange, or reddish incrustation. The number of affected spikelets in a head various greatly; only a single one may be affected or nearly all may be diseased. In fact, when the organism attacks any part of the rachis the entire head above the point of attack may be killed. This occurs quite frequently in a bad scab year. The affected portion of the rachis at first appears water-soaked, and later becomes dark in color. Still later the dark color may disappear and the rachis appear somewhat bleached. The small dark perithecia usually develop later in the season (Plate I, Fig. B).

The appearance of the affected kernels depends largely upon the age at which the head is attacked. If still very young, practically nothing but the seed coats may remain and these are often covered with the whitish or pinkish mycelium. If kernels develop they are usually very small, much shrunken, and can easily be crushed between the fingers. When the kernels become infected after they have developed to a considerable extent they may be less shrunken, but usually have the same general appearance as the badly shrunken kernels (Plate I, Fig. A).

The upper part of the culms also may be attacked. The symptoms are quite similar to those on the rachis. The affected tissues first appear water-soaked and later become brownish or almost black in color. When the neck is attacked early, the heads often fail to develop normally and practically no viable kernels are produced.

On rye, barley, oats, and grasses the symptoms are similar to those on wheat.

The seedling blight caused by scab fungi can not easily be distinguished from that caused by several other fungi. The plants usually are stunted, the root system is small, the individual rootlets are often brown or pink and may decay rapidly. The base of the young shoots also may be attacked, in which case the entire seedling dies.

Seedling blight often appears in definite patches in the field, and the plants in areas of considerable size are sometimes killed. This may be because the organism has accumulated in the soil, altho this has not been definitely proved. This occurrence apparently is associated with definite weather conditions. Unfavorable environment may allow the organism to reduce the stand greatly. Some of the attacked plants, however, may recover and mature if weather conditions again become favorable to the crop. Such plants may be stunted, but apparently are no more subject to head blight than are other plants.

## ETIOLOGY

The principal cause of wheat scab in Minnesota is probably *Gibberella saubinetii* (Mont.) Sacc. (*Fusarium graminearum*) Schwabe. This organism was found (15) to be primarily responsible for the epidemic which occurred throughout the middle western wheat growing regions in 1919. Other organisms, apparently quite distinct from this one, have been isolated from scabby wheat and their pathogenicity has been proved. Very little is known regarding the comparative virulence of these different species, nor is it known whether their life histories are comparable. It has been definitely proved, however, that at least one of the organisms causing root-, stalk-, and ear-rots of corn is the same organism as the one chiefly responsible for the epidemic of 1919. Furthermore, as will be shown later, this same organism is capable of attacking a very wide range of host plants. To what extent these other species are capable of doing the same thing is not known.

In the experimental work described in the following pages, except where otherwise specified, a strain of Fusarium isolated from scabby wheat and identified as *Gibberella saubinetii* was used exclusively.[3] In the field work, however, especially where controlled inoculations

[3] Identified by Dr. Sherbakoff.

were not made, the identity of the organism or organisms could not easily be determined.

## LIFE HISTORY OF ORGANISM AND SOURCES OF INFECTION

The complete life history, as far as spore forms are concerned, has been definitely determined for *Gibberella saubinetii*. In other cases only the conidial stages have been observed. An examination of Plate II will make clear the different stages through which *G. saubinetii* passes. Figure 1 shows the way in which the conidia are developed and Figure 2 the mature conidia germinating. In Figure 3 a few strands of the mycelium are represented. The second, or ascus, stage is illustrated by Figures 4 to 8. The conidia, the mycelium, and the spores formed in the ascus are all equally capable of causing infection, altho it seems probable that the ascospores, protected as they are by the perithecium (Fig. 4), are better able to resist unfavorable conditions than are the conidia.

It is clear, therefore, that infection may be brought about in several ways. Infected seed contains a large amount of mycelium which is capable of attacking any susceptible plant, and which may form spores if conditions are favorable.. Soil that has been under cultivation has been shown to contain large numbers of conidia which may attack the roots directly or may be blown by the wind and attack the heads. Conidia also may occur on a great variety of debris and thus form possible sources of infection. Furthermore, the perithecia occurring on old corn or wheat stubble are filled with ascospores which may be disseminated by the wind, by insects, or by other carriers.

To what extent these various sources of infection are important is not definitely known. It is extremely important, however, to determine the extent to which the conidia and mycelium of the organism are capable of living over winter and becoming a source of infection the following spring.

Scabby heads, infected kernels, and cultures of the organism were, therefore, kept outdoors at St. Paul during the winter of 1918-19 and similar experiments were made in 1919-20. The results are given in Tables I and II. Some heads, kernels, and cultures were kept in the laboratory, both in the dark and in the light, while others were kept under similar conditions outdoors. The mycelium and the spores retained their viability when they were kept in the dark inside and also when they were in the dark outside, but similar sets that had been exposed to the light were killed. The results show rather clearly that low temperatures alone are not sufficient to destroy the

organism, especially when the fungus is protected under rubbish or straw in the field, and it is quite probable that it lives over winter without difficulty. Undoubtedly, large quantities of spores and considerable mycelium are protected from the apparently injurious effect of light, and can, therefore, develop normally when conditions are again favorable for growth.

TABLE I

EFFECT OF EXPOSURE ON VITALITY OF THE MYCELIUM OF *Gibberella saubinetii* IN SEEDS OF WHEAT

| Kind of Seed | Location of material | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Ice box 10° C. | | Thermostat 25° C. | | Cold storeroom | | Outside on ground | |
| | A* | B | A | B | A | B | A | B |
| Healthy ..... | —† | | — | | — | | — | |
| Scabby ..... | + | — | + | — | + | — | + | — |
| Scabby ..... | + | | + | | + | | + | |
| Scabby ..... | + | | + | | + | | + | |
| Inoculated ..... | | + | + | + | + | + | + | + |
| Inoculated ..... | + | + | + | | + | + | + | — |
| Inoculated ..... | + | | + | | + | | + | + |

* A — Exposed from October 1917 to April 1918 (6 months).
B — Exposed from October 1917 to April 1919 (18 months).
† + Organism alive when tested.
— Organism dead when tested.

TABLE II

EFFECT OF LIGHT ON VIABILITY OF CONIDIA OF *Gibberella saubinetii* EXPOSED UNDER VARIOUS CONDITIONS FROM OCTOBER, 1917, TO APRIL, 1918

| Conditions under which kept and percentage of germination | | | |
|---|---|---|---|
| Light | | Dark | |
| Laboratory | Field | Laboratory | Field |
| 0.0 | 0 | 50.0 | 100 |
| 1.0 | 0 | 75.0 | 100 |
| 0.5 | 0 | 0.5 | 90 |
| 0.0 | 0 | 85.0 | 100 |
| 0.0 | 0 | 25.0 | 50 |
| 0.0 | 0 | 100.0 | 90 |
| 0.0 | 0 | 25.0 | 50 |
| Average 0.2 | 0 | 51.0 | 83 |

## EFFECT OF TEMPERATURE

Temperature and moisture are known to be important factors in relation to scab on wheat. The disease is usually most prevalent in moist hot seasons. Experiments conducted in the field and laboratory were designed particularly to find the extent to which temperature is a factor in its development. No controlled experiments were made to

correlate moisture and temperature with the development of scab, altho observation suggested very definitely that the disease is favored by high humidity when temperature conditions are right.

## INFLUENCE OF TEMPERATURE ON ORGANISM

The rate of growth of the wheat scab organism on artificial media was studied at different temperatures. It was found that the organism grew most rapidly at temperatures between 25 and 27 degrees C. (77 to 80 degrees F.). At 30 degrees C. (86 degrees F.) the rate of growth is greatly decreased and the character of the mycelium produced is different from that produced at lower temperatures. No growth was obtained at 35 degrees C. (95 degrees F.). Dickson (7) found that the organism was killed at 33 to 34 degrees C. (91 to 93 degrees F.). On the other hand, the organism grows very slowly at 5 degrees C. (41 degrees F.) and according to Dickson does not grow at all at 3 degrees C. (38 degrees F.). These results obtained by the writers are shown in Table III and in Figure 2. (See also Plate III, Fig. A.)

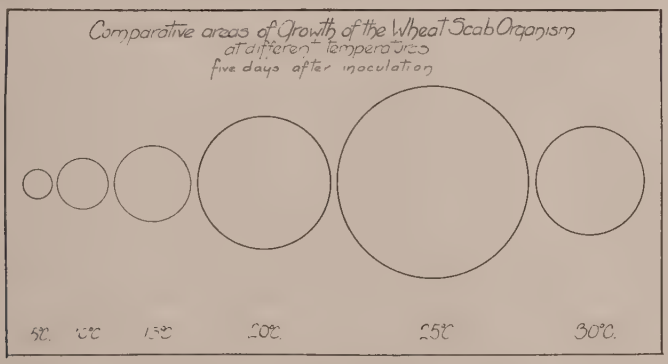


Fig. 2. Growth of Mycelium of *Gibberella saubinetii* in Relation to Temperature

TABLE III

EFFECT OF TEMPERATURE ON GROWTH OF *Gibberella saubinetii* ON CULTURE MEDIA

| Temperature in degrees C. | Time after inoculation in days | | | | | |
|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 |
| | Diameter of colonies in centimeters* | | | | | |
| 5.0 | † | † | † | † | | |
| 10.0 | † | 0.6 | 1.6 | 1.9 | 2.5 | 2.5 |
| 15.0 | 1.0 | 1.5 | 2.5 | 2.7 | 3.0 | 3.5 |
| 20.0 | 1.0 | 2.5 | 3.7 | 5.7 | 6.8 | 8.0 |
| 25.0 | 1.2 | 3.0 | 5.6 | 8.2 | 9.9 | .. |
| 27.5 | 1.3 | 4.0 | 3.9 | 6.6 | 8.5 | 10.0 |
| 30.0 | 0.8 | 2.4 | 4.1 | 5.9 | 6.0 | 6.5 |

* Figures based on averages of from 4 to 10 experiments.

† Trace.

Spore germination was found to occur most rapidly at temperatures near the optimum for growth of the mycelium (Table IV, and Fig. 3). At 25 degrees C. (77 degrees F.), practically 100 per cent of the spores germinated and the germ tubes were well developed aftr 48 hours; while at 10 degrees C. (50 degrees F.) only 40 per cent had germinated, the germ tubes being very short. Temperatures above 30 degrees C. (86 degrees F.) were found to decrease the percentage of germination as well as the length of the germ tube. However, practically all the spores eventually germinated at all the temperatures tried.

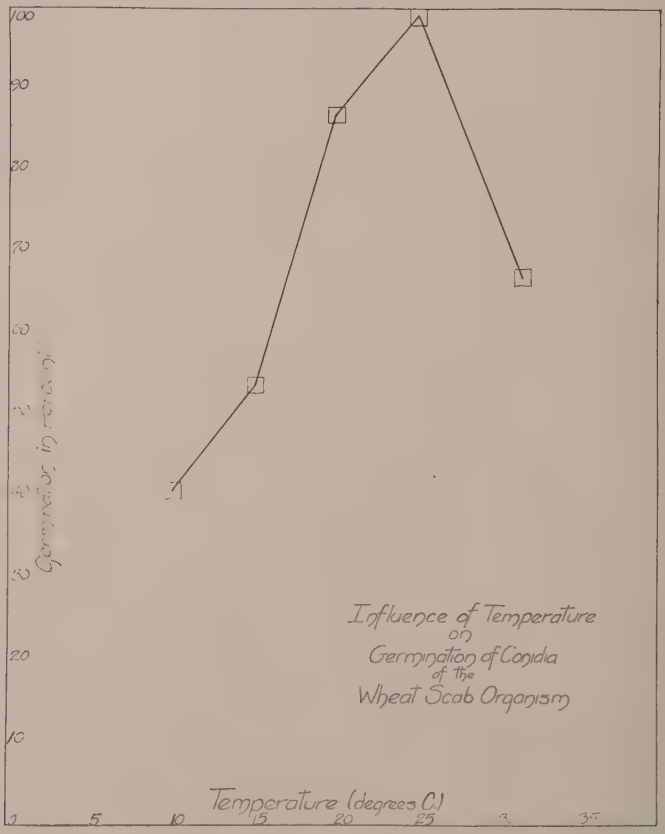


Fig. 3. Germination of Conidia of *Gibberella saubinetii* in Relation to Temperature Note that the optimum temperature is the same as for the growth of the mycelium.

TABLE IV

EFFECT OF TEMPERATURE ON GERMINATION OF CONIDIA OF *Gibberella saubinetii* IN DISTILLED WATER

| Temperature in degrees C. | No. of spores counted | No. of spores germinated* | Percentage of germination |
|---|---|---|---|
| 10 | 448 | 183 | 41 |
| 15 | 364 | 200 | 54 |
| 20 | 179 | 156 | 89 |
| 25 | 350 | 350 | 100 |
| 33 | 232 | 157 | 67 |

* Counts made at the end of 48 hours.

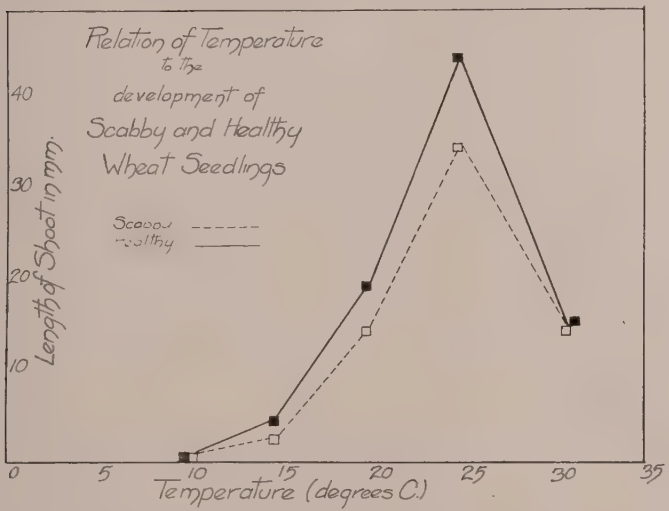


Fig. 4. Growth of Wheat Seedlings in Relation to Temperature

The shoots produced from scabby seeds were markedly stunted at temperatures favorable for the organism. At 30 degrees C., altho the plants grew slowly because of the high temperature, the seedlings from scabby seeds grew as rapidly as those from healthy seeds.

## INFLUENCE OF TEMPERATURE ON GERMINATION OF WHEAT SEED

According to Dickson (15) wheat germinated normally at temperatures between 8 and 24 degrees C. (46 and 75 degrees F.), the rate of germination increasing up to 32 degrees C. (89 degrees F.). The results of the experiments carried out by the writers are more or less in accordance with those found by Dickson. The percentage of germination of the wheat kernel was not materially affected by temperatures between 5 and 33 degrees C. (41 and 91 degrees F.). The rate of development, however, was greatly changed (Table V) (Fig. 4). After four days in the germinator the shoots from seeds kept at 25

degrees C. (77 degrees F.) were from eight to ten times as long as those kept at 15 degrees C. (59 degrees F.). At 33 degrees C. (91 degrees F.) the rate was decreased considerably. At 5 and 10 degrees C. (41 and 50 degrees F.) they had not developed at all. However, if sufficient time was allowed, normal germination took place even at these low temperatures.

TABLE V

EFFECT OF TEMPERATURE ON GERMINATION OF WHEAT SEED AND ON DEVELOPMENT OF SCAB

| Temperature in degrees C. | Kind of seed planted* | Percentage of germination† | Av. length of epicotyl in mm. | Percentage of blighted seedlings |
|---|---|---|---|---|
| 5 | Scabby | 0 | 0 | 0.0 |
| | Healthy | 0 | 0 | 0.0 |
| 10 | Scabby | 0 | 0 | 0.0 |
| | Healthy | 0 | 0 | 0.0 |
| 15-16 | Scabby | 83 | 3 | 6.5 |
| | Healthy | 92 | 5 | 0.0 |
| 18-20 | Scabby | 79 | 15 | 7.3 |
| | Healthy | 98 | 20 | 0.0 |
| 25 | Scabby | 78 | 35 | 7.3 |
| | Healthy | 98 | 45 | 0.0 |
| 32-33 | Scabby | 79 | 15 | 2.0 |
| | Healthy | 96 | 15 | 0.0 |

* Seeds were planted in sterilized soil.
† At the end of four days.

## INFLUENCE OF TEMPERATURE ON DEVELOPMENT OF SEEDLINGS FROM HEALTHY AND SCABBY KERNELS

Attention has been drawn to the fact that when scabby seed is germinated under normal conditions, considerable fungus growth develops, often in quantities sufficient to destroy the seedlings. It was found, however, that the amount of fungus growth thus produced varied considerably with the temperatures at which germination occurred. When scabby grain was germinated at temperatures between 30 and 33 degrees C. (86 and 91 degrees F.) relatively little fungus growth was produced and the young shoots in most cases escaped injury. Considerable mycelium was produced at temperatures from 20 to 30 degrees C. (68 to 86 degrees F.) usually in amounts sufficient to destroy the shoots and roots of the young seedlings in less than one week. From 10 to 15 degrees C. (50 to 59 degrees F.), however, the rate of fungus growth was considerably slower, and the seedlings usually developed too rapidly for the organism to attack them. It is seen, therefore, that temperature is an extremely important factor in determining the number of seedlings that will be killed, and that good growth may be obtained even when the organism is present, if the temperature is

unfavorable to its growth. In order to demonstrate that the blighting of the seedlings was due directly to the presence of the organism and not to the shrunken condition of the seeds, a number of plump healthy seeds were sterilized and germinated.[4] Half of these were then inoculated with the wheat scab organism, and grown at different temperatures, the other half being retained as checks (Plate III, Fig. B.). The results (Table VI) were identical with those obtained when scabby seeds were used. Similar results were obtained also when scabby seeds were planted in pots and germinated at different temperatures (Table VII). It is obvious, therefore, that the blighting of the seedlings is due to the presence of the scab organisms and that the activities of these organisms are directly limited by temperature conditions.

No controlled experiments have been carried out to show the relation of temperature to the development of scab on the heads. However, observations in the field seem to indicate that more scab is produced at temperatures near the optimum for the growth of the organism than at other temperatures.

[4] The following method for obtaining sterile seedlings was used: Seeds were soaked in distilled water for thirty minutes. They were then immersed in 50 per cent alcohol containing 0.2 per cent mercuric bichloride. After washing in sterile distilled water, the seeds were put in petri dishes. The sterile germinating seeds were transferred to test tubes, containing agar, after four days' growth.

TABLE VI

EFFECT OF TEMPERATURE ON BLIGHTING OF SEEDLINGS GROWN IN SACH'S NUTRIENT AGAR AND INOCULATED WITH *Gibberella saubinetii*

| Temperature in degrees C. | Condition of seedlings and growth of organism | | | |
|---|---|---|---|---|
| | Third day | | Seventh day | |
| | Average length of epicotyl in cm. | Average length of root system in cm. | Development of of organism | Remarks |
| 10 | 1.0 | 49 | Nearly covering medium, growth slight. | Some aerial roots browned. *Check* clean. |
| 15-16 | 3.5 | 120 | Well developed. | Some roots in the medium. Three plants growing, three killed. *Check* growing out of tube. |
| 18-20 | 2.4 | * | Luxuriant. | Few roots developed, only one plant more or less escaping the organism. In all other cases both roots and plant killed. *Check* growing out of tube. |
| 25 | 3.3 | * | Very luxuriant growth. | Very few roots in the medium. All plants killed. Whole seedling browned. *Check* growing out of tube. |
| 20-30† | 3.1 | * | About as 18-20 degrees C. | Very similar in development to plants kept at 18-20 degrees C. More root development. *Check* growing out of tube. |
| 32-33 | 2.4 | 70 | Slow, not covering medium. | All plants grown to top of tube. Roots in contact with organism killed, no others. Epicotyl normal. Many normal roots. *Check* growing out of tube. |

* Difficult to estimate, owing to growth of organism.

† Twenty degrees C. at night, 30 degrees in the day.

TABLE VII

EFFECT OF TEMPERATURE ON GERMINATION OF HEALTHY AND SCABBY SEED IN STERILIZED SOIL

| Temperature in degrees C. | Kind of seed | No. of seeds planted | No. of seeds germinated | Percentage of germination | Av. length of epicotyl in cm. |
|---|---|---|---|---|---|
| 10-12 | Scabby | 40 | 0 | 0 | 0.0 |
| | Healthy | 40 | 0 | 0 | 0.0 |
| 15-16 | Scabby | 40 | 6 | 15 | 0.3 |
| | Healthy | 40 | 14 | 35 | 1.5 |
| 18-20 | Scabby | 40 | 18 | 45 | 9.5 |
| | Healthy | 40 | 17 | 42 | 8.2 |
| 25 | Scabby | 40 | 11 | 27 | 7.4 |
| | Healthy | 40 | 33 | 80 | 12.1 |
| 32-33 | Scabby | 40 | 12 | 30 | 3.5 |
| | Healthy | 40 | 15 | 37 | 5.7 |

## HOST PLANTS

It is evident from the historical summary that the organisms causing wheat scab can attack a great many plants other than wheat. Typical scab on the heads has been found in Minnesota on various types of wheat, rye, barley, oats, spelt, emmer, einkorn, and several grasses. It has seldom, if ever, been abundant enough on oats to do any appreciable damage. On rye, however, it sometimes causes considerable injury and occasionally also on barley. It occurs commonly on several wild grasses. Local epidemics of the disease have been seen frequently on western wheat grass (*Agropyron smithii*) and it also occurs on quack grass (*Agropyron repens*), slender wheat grass (*Agropyron tenerum*), and some of the wild rye grasses (*Elymus spp.*). The organism also attacks corn, especially the roots, altho this disease apparently is not so prevalent in Minnesota as it is in the more southern portions of the corn belt. It was of particular interest to ascertain by means of artificial inoculations whether or not the organism could be made to attack plants other than those on which it is found in nature. A series of experiments was, therefore, carried out, in both field and laboratory, in which a large number of plants widely separated taxonomically were inoculated. In Table VIII are listed all the host plants on which the disease has been found in nature in Minnesota, and also those that have been infected as a result of artificial inoculations.

TABLE VIII

HOST PLANTS OF WHEAT SCAB ORGANISMS

| Host plant | Artificial inoculation | Natural infection | Type of injury |
|---|---|---|---|
| Wheat— | | | |
| *Triticum vulgare* | + | + | Head blight and seedling blight |
| *T. durum* | + | + | Head blight and seedling blight |
| *T. spelta* | .. | + | Head blight |
| *T. dicoccum* | + | + | Head blight |
| *T. monococcum* | .. | + | Head blight |
| *T. polonicum* | .. | + | Head blight |
| *T. compactum* | + | + | Head blight |
| *T. turgidum* | .. | + | Head blight |
| Rye—*Secale cereale* | + | + | Head blight and seedling blight |
| Barley—*Hordeum vulgare* | + | + | Head blight |
| Oats—*Avena sativa* | + | + | Head blight |
| Grasses— | | | |
| *Agropyron caninum* | .. | + | Head blight |
| *A. smithii* | + | + | Head blight |
| *A. cristatum* | + | .. | Head blight |
| *A. desertorum* | + | .. | Head blight |
| *A. repens* | + | .. | Head blight |
| *Alopecurus pratensis* | + | .. | Leaf spot |
| *Phleum pratense* | + | .. | Leaf spot |
| *Bromus inermis* | + | .. | Leaf spot |
| *Hystrix patula* | + | .. | Leaf spot |
| *Elymus canadensis* | + | .. | Head blight |
| *E. robustus* | + | .. | Head blight |
| *E. virginicus* | + | .. | Head blight |
| Corn—*Zea mays* | + | + | Root rot |
| Bean—*Phaseolus vulgaris* | + | .. | Root, pod, leaf and stem rots |
| Apple—*Malus sylvestris* | + | .. | Fruit rot |
| Carrot—*Daucus carota* | + | .. | Rot of storage organ |
| Potato—*Solanum tuberosum* | + | .. | Tuber rot |
| Pea—*Pisum sativum* | + | .. | Stem rot and seedling blight |
| Clover—*Trifolium pratense* | + | .. | Seedling blight |
| Tomato—*Lycopersicum esculentum* | + | .. | Stem and leaf rots and seedling blight |
| Flax—*Linum usitatissimum* | + | .. | Seedling blight |
| Cucumber—*Cucumis sativus* | + | .. | Stem rot and seedling blight |
| Squash—*Cucurbita maxima* | + | .. | Stem rot |
| Sunflower—*Helianthus annuus* | + | .. | Stem rot |
| Radish—*Raphanus sativus* | + | .. | Seedling blight |

## PARASITIC CAPABILITIES OF THE ORGANISM

The effect produced on the different hosts and different parts of the same host by artificial inoculation varied considerably. The methods of experimentation and types of injury obtained on the various hosts are given below.

## INFECTION OF FRUITS AND TUBERS

The fact that *Fusarium culmorum* is capable of causing a rot of the potato tuber has been demonstrated by several investigators (7, 31, 36). In order to determine whether the scab organism used in this study could produce such a rot, and to compare the rate of rotting with that produced by Fusaria generally found causing tuber rots, several sound potato tubers were inoculated with *Gibberella saubinetii* and with *F. oxysporum* and *F. tricothecioides*. One tuber was also retained as a check. These tubers were then placed under a bell jar and kept at a temperature ranging from 25 to 28 degrees C.

It was found that all three organisms were exceedingly active in rotting potato tubers. *Gibberella saubinetii* produced a very extensive rot within six weeks after inoculation (Plate V, Fig. E) which was second only to the one produced by *F. tricothecioides*. The scab organism was also found to produce rots on carrots and apples. These rots were less extensive than that produced in the potato tubers, but nevertheless they were definite in character and indicative of the rot-inducing nature of the organism. Lewis (17) reports finding the scab organism causing a serious rot of squash in storage.

The fact that an organism is capable of causing a rot of storage organs, such as potato tubers, is not sufficient proof in itself that the organism under consideration is a virulent parasite. Successful infection of the living parts of a plant is necessary in determining the true parasitic nature of the attacking organism.

### INFECTION THROUGH WOUNDS

The stems and leaves of several hosts were punctured and bits of mycelium of the wheat scab organism introduced into the wounds. The plants were than incubated in a moist chamber. The mycelium made considerable growth and spread into the tissues while in the incubation chamber. The plants fell over at the point of inoculation owing to the weakening of the tissues following the spread of the mycelium through them. Eventual death of the plant resulted in nearly all cases. Inoculation experiments similar to those described above were also carried out with *F. lini*, the flax wilt organism, and *F. martii*, known to cause root rot of beans, to determine whether any other Fusarium known to cause injury to a specific crop, was capable of attacking a wide range of hosts as are the scab organisms. Both *F. martii* and *F. lini* seem to be specialized and limited in their parasitic capabilities, as far as tested, to attacking the roots of beans in the former and to the roots and leaves of the flax seedling in the latter. All the crops tested, other than those mentioned, seemed incapable of being parasitized by these organisms.

Plate V, Figures A1 and A2 show the effect of stem inoculation upon the bean plant, two weeks after inoculation. The shriveling of the stem is shown to have extended in both directions from the point of inoculation, the parts above being shriveled and dead. Attention is especially called to the healthy check plant (Fig. A). The punctures show very distinctly and indicate clearly that the death of the infected plants was not the result of the injury to the stem. Figures C and D show similar effects of the organism upon tomato and cucumber plants three days after inoculation.

Plate VI, Figure A, shows the wheat scab organism parasitizing the living parts of pea plants. The two plants in the pots to the left were yellow and dead, the one in the pot to the right remained healthy and green. Fig. B, of the same plate, shows the effect of scab cultures upon sunflower seedlings the stems of which had been inoculated ten days previously. The plants in the first and seventh pots, counting from the left, are check plants. The one in the third was inoculated with *F. lini*. It will be noted that these checks and the one inoculated with *F. lini* were the only ones that remained alive and vigorous.

Figure C shows the effect of the scab organism on squash plants. The check plant is in the pot to the right. The stem of the plant in the center pot is dead as a consequence of the successful infection. These two are shriveled and dead as a result of the infection, while those inoculated with *F. lini* are as healthy and vigorous as those of the check plant. This points once more to the difference in the virulence of the two organisms; to the specific limitations of the one and the wide adaptability of the other.

### INFECTION OF UNINJURED TISSUES

The facts brought out in the above experiments show clearly the ability of the scab organisms to attack diverse crops and their extreme virulence as wound parasites. Scab of wheat is known to appear on uninjured heads of wheat. This would indicate that the wheat scab organism did not depend upon previous wounding of the tissues. However, tests were made on several hosts to test this point conclusively.

Artificial inoculations on individual heads of different varieties of wheat and several wild grasses were made in the field. Inoculations were made by inserting a small amount of the fungus (*Gibberella saubinetii*) inside the sheath, only those heads being chosen which had not completely emerged. Care was taken not to injure either the sheath or the head. Moist cotton was then wrapped around the sheath, the whole being covered with a wax-paper bag. These covers were left on for periods varying from three to seven days. By this method successful infections were obtained on several varieties of common wheat

(*T. vulgare*) as well as on durum (*T. durum*), emmer (*T. dicoccum*), and club (*T. compactum*) wheats. Rye, barley, oats, and several wild grasses were similarly infected (Table VIII).

It seems quite probable that the list of susceptible grasses given in Table VIII could be greatly enlarged if inoculations were made at the proper time. Many of the negative results obtained were without doubt due to the fact that the heads were too old at the time of inoculation. In every case, however, in which the inoculation gave positive results the heads were attacked in a manner exactly similar to natural infection. The effects shown in Plate IV are characteristic of the results obtained. A pink incrustation developed on the glumes, and the kernels either did not form or were small, shriveled, and covered with a mass of pinkish white mycelium. Typical scab also developed on all the varieties of wheat and other cereals inoculated, altho some of the varieties of wheat were more heavily infected than others. So many factors might be involved in this variation that no definite conclusions can be drawn.

Leaf spots were obtained in several cases and pure cultures of the organism were isolated from them.

The uninjured leaves of tomato and bean plants growing in the greenhouse were inoculated by placing growing mycelium on the surface. The upper surface of some leaves was inoculated and the lower surface of others. Upon removal from the incubating chamber, the fungus was found to have produced definite spots. The growth of the organism extended through the leaf, and pure cultures of the organism were readily obtained.

A vigorously growing bean pod was similarly inoculated without injury to the tissues. The mycelium spread throughout the pod, shriveling it. Pure cultures were obtained from the uninoculated side of the pod, indicating the extent of the spread of the mycelium through the tissues.

While these observations are preliminary in their nature, they are indicative of the fact that under certain conditions the scab organism may and actually does attack uninjured tissues.

## INFECTION BY SOIL INOCULATION

### A. DAMPING-OFF AND SEEDLING BLIGHT

Previous experiments show beyond doubt that the scab organism is a virulent parasite, and that it attacks a large number of unrelated hosts. Attention has been called by many investigators to the fact that *Fusarium spp.* are to be found connected with the damping-off of the seedlings of a large number of crops. The fact that the wheat scab organism is capable of attacking the seedlings of small grains has already

been brought out. Efforts were made to determine whether the scab organism was capable of inducing such damping-off of hosts other than wheat.

The question of sick soils and the part played by the wheat scab organism in their production has already been discussed. This condition can be approximated closely by heavy inoculation of soil in pots. The soil was sterilized under steam pressure previous to inoculation in order to kill any organisms which might already be in the soil.

White clover was planted in such sterilized soil, the soil of one pot being inoculated with the scab organism, while that of the other was retained as a check. Two weeks after inoculation it was quite evident that the scab organism was killing many of the clover seedlings. The stems and roots of a large number of these were discolored and were beginning to rot. These dead parts were infected with the wheat scab pathogene. Plate V, Fig. B1 and B2, shows two such pots two weeks after inoculation. The effects were even more striking than the plates would indicate, altho the difference between the checks and the inoculated plants is very striking. Nearly half the plants in the inoculated pot were killed and the rest were stunted.

Pea, tomato, radish, cucumber, and flax seedlings were also grown under similar conditions. The flax wilt organism (*Fusarium lini*) was inoculated into the soil of one pot of each of these hosts in order to compare the parasitic capabilities of this organism with those of the scab organism. Typical wilt was produced on flax, some of the cotyledons becoming infected as they pushed their way through the sick soil, but no such wilt occurred on any of the other hosts. The scab organism, however, was capable of attacking and causing a seedling blight of all of these plants.

### B. ROOT-ROTS

A disease known as dry root-rot of bean is caused by *Fusarium martii phaseoli*. To determine whether the wheat scab organism was also capable of attacking the roots of this host, several pots of soil were sterilized and beans grown in them. The soil of one of these pots was then inoculated with the wheat scab organism, that of a second with *F. martii*, and the third was retained as a check.

No important differences between the plants in the three pots were discernible until about six weeks after inoculation. By that time, however, many of the leaves of the inoculated plants had turned yellow and dropped off. These appeared less vigorous than did the plants in the check pot.

All the plants were then dug up (Plate VII, Fig. A). The stems and roots of the plants inoculated with *F. martii* showed large dark brown lesions, many of the roots having been killed and the whole root

system reduced. This disease resembled very closely the condition described as dry root-rot. The plants from the pot inoculated with the scab culture (marked 200c in Plate VII, Fig. A) showed the same discolorations and reduction of the root system, only to a slightly less extent. The stems from both inoculated pots were beginning to shrivel and turn yellow, while those in the check pot, it will be noted, were entirely normal; and the root system, which was much better developed, showed no discolorations.

Several investigators have called attention to the fact that wheat scab is intimately connected with corn root-rot. Experiments were therefore made to determine whether the wheat scab organism used in these studies could produce this root-rot. Corn was planted in pots of sterile soil. The soil in some of these pots was then made sick with the wheat scab organism used in the inoculations on the roots of beans. The remaining pots were retained as checks. All the plants were then grown to maturity.

The plants in the inoculated pots were stunted in appearance during the whole period under observation, as compared with the check plants. (Plate VIII.) There was an average difference of 15 cm. in height between the two series of plants, the inoculated plants producing tassels two weeks later than the ones growing in the healthy soil. When the roots of the inoculated plants were examined they were found to be dark brown, shriveled, and beginning to rot, while those of the check plants were normal in every respect.

In order to study this root-rot more carefully, several pots of corn seedlings were inoculated with a wheat scab culture and an equal number were retained as checks. All the roots were examined a month later. The primary roots of the plants grown in the inoculated soil were dark brown, shriveled, and dead. Many secondary roots were similarly affected. Isolations made from these lesions yielded pure cultures of the scab organism. The roots of the check plants, however, were more numerous, better developed, and perfectly healthy. (Plate VII, Fig. B.)

## CONTROL

No entirely satisfactory methods of control of wheat scab are known. The problem is greatly complicated by the number of hosts which the organisms causing the disease are capable of attacking and also because these organisms can grow saprophytically on almost any kind of debris.

Various measures have been suggested by workers in this country, such as burning of stubble, cleaning of seed, rotation of crops, etc., but none of these has controlled the disease, altho without doubt, under certain conditions, they would help to prevent its spread. Experiments

were carried out in the field and in the greenhouse to test the efficiency of these methods. The results are rather contradictory in some cases and many of the experiments would have to be extended over several years before definite conclusions could be drawn. However, they are suggestive and may be of value in interpreting future work.

## CLEANING AND TREATING SEED

In 1917 and 1918 the shriveled kernels from scabby seed were separated from the plump kernels by fanning, and part of each grade was treated with formaldehyde. One square rod each of the treated and untreated lots was planted. The results given in Table IX indicate that treatment of seed has no effect on the appearance of scab on the mature heads, the plots of treated seed in these experiments having a slightly higher percentage of scab than those of untreated seed. However, an examination of Table X, a record of plants grown under controlled conditions in the greenhouse, will show that treatment with formaldehyde materially increases the percentage of germination of scabby seed altho no scab appeared on any of the mature plants. The results shown in Plate IX are typical of those obtained in this experiment.

Planting scabby, untreated seed lowers the average germination of the seed and healthy seedlings may be attacked by the organism and be killed in the soil. Treatment, therefore, may be of some value in preventing seedling blight. The plants that survive the seedling stage, however, apparently may grow to maturity and produce healthy seed unless subsequently infected. In other words, infection is local and not systemic.

## ROTATION OF CROPS

Many organisms causing plant diseases are known to accumulate in the soil when crops on which they are capable of developing are grown on the same land for a succession of years. This is particularly true of organisms causing root-rots and of those that are able to live saprophytically during a part of their life. The organisms causing wheat scab are known to be abundant in soil in which wheat has been grown for a long time.

TABLE IX

EFFECT OF PLANTING TREATED AND UNTREATED SEED IN THE FIELD ON THE PERCENTAGE OF SCABBY HEADS

| Kind of seed | Treatment | | | |
|---|---|---|---|---|
| | Formaldehyde (1:320) | | None | |
| | Percentage of scabby heads | | | |
| | 1917 | 1918 | 1917 | 1918 |
| Healthy | 1.66 | 0.79 | 0.35 | 0.79 |
| Scabby | 1.12 | 1.14 | 0.80 | 0.21 |

TABLE X

EFFECT OF TREATMENT WITH FORMALDEHYDE ON PERCENTAGE OF GERMINATION OF WHEAT SEEDS AND ON PERCENTAGE OF SCAB AT MATURITY*

| Kind of seed | Treatment | No. of pots | No. of seeds per pot | Percentage of germination | Percentage of scab at maturity |
|---|---|---|---|---|---|
| Healthy | None | 25 | 10 | 89.6 | 0 |
| Scabby | Formaldehyde† | 25 | 10 | 81.6 | 0 |
| Scabby | None | 25 | 10 | 21.2 | 0 |

* Unpublished data from observations made in the greenhouse in the winter of 1917 by W. N. Christopher.

† Strength 1:320.

In 1918, in Indiana, Hoffer, Johnson and Atanasoff (11) observed that the percentage of scab on wheat that was planted on land where root-rot of corn had been prevalent the year before was much higher than on wheat following other crops. Inoculation experiments proved that the organism causing corn root-rot was identical with one of the organisms which cause wheat scab and was capable of producing scab on wheat. These results were very suggestive as to a method of spread of the disease. In 1919 a careful summary of the plant disease survey of Minnesota made by the United States Department of Agriculture showed a much higher average percentage of scab on wheat grown on corn land than on wheat grown after either wheat, rye, or barley (Table XI). Results for several years must be obtained before definite conclusions can be drawn, but it is possible that the organism can very readily live over winter on diseased corn stubble and be in a condition to attack the susceptible wheat plant as it matures.

TABLE XI

EFFECT OF ROTATION ON PERCENTAGE OF SCAB ON WHEAT IN MINNESOTA IN 1919*

| Previous crops | No. of fields visited | Average percentage of diseased heads | Yield in bushels per acre |
|---|---|---|---|
| Corn | 193 | 23.53 | 5.62 |
| Wheat | 95 | 7.42 | 11.23 |
| Oats | 67 | 10.81 | 10.03 |
| Barley | 20 | 11.15 | 10.75 |

* Data taken from the Plant Disease Survey of the United States Department of Agriculture for the year 1919.

## VARIETAL RESISTANCE OF WHEAT

Many plant diseases have been very effectively controlled by the use of varieties which were more or less resistant to these diseases. Wheat scab is much more prevalent on some varieties of wheat than on others. Observations throughout the state as well as controlled experiments in the field and greenhouse have been made for several years. Prior to 1914, scab seemed to be really destructive in Minnesota only to durum

wheats, but as soon as Marquis was introduced, farmers complained that this variety was more severely injured than any of the other common spring wheats. In 1919 there was a destructive epidemic of scab in the southern half of Minnesota. In Meeker and Kandiyohi counties, counts were made of the percentage of scabby heads in several neighboring fields of Marquis, Haynes bluestem, and Preston. The percentage of scabby heads, as well as of blighted spikelets, was consistently higher in Marquis than in the other two varieties. The percentage of scabby heads in Marquis ranged from 50 to 90, while that in the other varieties seldom exceeded 25. This might be because conditions for infection were more favorable when Marquis was in flower, but, whatever the cause, Marquis was more severely injured than the other two varieties.[5] These results are similar to the averages obtained by the Plant Disease Survey for the whole state in 1919 (Table XII).

TABLE XII

VARIETAL SUSCEPTIBILITY OF WHEAT TO SCAB IN MINNESOTA IN 1919*

| Variety | No. of fields visited | Average percentage of scab |
|---|---|---|
| Marquis | 325 | 16.80 |
| Preston | 83 | 12.74 |
| Durum | 19 | 4.97 |
| Haynes bluestem | 12 | 1.40 |

* Data from Plant Disease Survey of 1919.

In order to determine more accurately the comparative susceptibility of wheat varieties to scab, attempts were made at University Farm to develop artificial epidemics. Different varieties of wheat were grown on corn land and the emerging heads were sprayed with a suspension of spores of various scab-producing organisms. Unfortunately, it was not possible to obtain as high a percentage of scab as would be desirable for accurate conclusions. The data are therefore preliminary, but some indications of comparative susceptibility were obtained. Tests were made in 1917, 1918, 1919, 1920, and 1921, but only in 1918 and 1921 did enough scab develop to warrant any conclusions. The results are summarized in Tables XIII and XIV.

[5] Observations made by E. C. Stakman H. K. Hayes, and R. J. Garber.

TABLE XIII

RELATIVE PERCENTAGE OF SCAB ON VARIETIES OF WHEAT ARTIFICIALLY INOCULATED IN THE FIELD IN 1918

| Variety | No. of heads counted | No. of scabby heads | Percentage of scabby heads |
|---|---|---|---|
| Mindum, Minn. 470 | 740 | 117 | 16.2 |
| Glyndon Fife, Minn. 163 | 923 | 27 | 3.0 |
| Preston, Minn. 188 | 873 | 22 | 2.6 |
| Marquis, Minn. 1239 | 1067 | 24 | 2.2 |
| Velvet Don, Minn. 1364 | 814 | 18 | 2.1 |
| Stanley, Minn, 1594 | 883 | 8 | 0.9 |

TABLE XIV

COMPARATIVE RESISTANCE OF WHEAT VARIETIES TO SCAB AT UNIVERSITY FARM IN 1921*

| Variety | Percentage of scabby heads | | Percentage of scabby seeds from infected heads | |
|---|---|---|---|---|
| | A† | B† | A | B |
| Preston, Minn. 924 | 0.0 | 0.5 | 0.0 | 3.0 |
| Haynes Bluestem, Minn. 169 | 1.0 | 0.5 | 9.0 | 4.0 |
| Glyndon Fife, Minn. 163 | 1.5 | 0.0 | 11.0 | 0.0 |
| Kota, C. I. 5878 | 1.5 | 3.0 | 8.0 | 9.8 |
| Kitchener, C. I. 2153 | 2.5 | 1.5 | 10.3 | 10.5 |
| Ruby, C. I. 2151 | 2.5 | 3.0 | 28.0 | 18.0 |
| Prelude, C. I. 4323 | 2.9 | 3.6 | 8.1 | 15.0 |
| Red Bobs, C. I. 6255 | 2.5 | 8.3 | 11.0 | 23.0 |
| Red Durum, selection | 3.0 | 11.0 | 12.0 | 12.1 |
| Marquis, Minn. 1239 | 4.5 | 9.5 | 19.0 | 18.0 |
| Acme, C. I. 1967 | 6.5 | 8.5 | 19.0 | 12.3 |
| Kubanka, C. I. 2102 | 8.8 | 7.9 | 27.7 | 10.0 |
| Monad, C. I. 2156 | 12.0 | 10.0 | 18.0 | 14.5 |
| Mindum, Minn. 470 | 14.5 | 9.0 | 14.1 | 16.6 |
| Kubanka, C. I. 2094 | 19.5 | 14.0 | 13.0 | 18.8 |
| Kubanka, (8) C. I. 4063 | ... | 25.4 | ... | 11.4 |

* Data furnished by J. J. Christensen.

†A. Planted April 23, 1921.

B. Planted May 10, 1921.

## DISCUSSION OF CONTROL MEASURES

It is evident that control of wheat scab is difficult for the following reasons: The organism may grow on a great many cultivated and wild hosts; it may live as a saprophyte on dead materials; it may live a long time even under comparatively unfavorable conditions; and it is easily distributed by the wind and other carriers. The only methods of control that can be recommended at present are thoro fanning and treatment of seed grain, proper crop rotation, and the use of resistant varieties.

While scab can not be controlled entirely by the use of clean seed, the amount of seedling blight can be reduced considerably if only healthy plump seed is sown. Seed grain should be fanned very thoroly in order to blow out all the light, shriveled kernels. The treatment used for the control of stinking smut will kill any spores on the surface of the seed. Very badly scabbed seed lots should not be planted. Wherever possible seed should be obtained from fields in which there had been very little scab.

Rotation of crops is important in controlling the disease. It has been found that scab in wheat is likely to be much more severe when this crop follows corn. In fact, scab is likely to be more prevalent in wheat that is grown on corn land than in wheat which follows wheat or other cereal crops. While it would be unwise to recommend that wheat should never follow corn, it seems perfectly clear that in those regions in which scab is destructive nearly every year the amount of damage could be reduced considerably if some system of rotation were devised which would avoid sowing wheat on corn land.

Early sowing may aid somewhat in keeping down the amount of seedling blight. The fungus which causes scab is likely to develop most profusely at fairly high soil temperatures. Early sowing, therefore, is likely to enable the wheat to grow away from the scab.

Sanitation is quite important. It should be remembered that the scab organism attacks a great many wild grasses as well as the small grains and corn. For this reason it would be well to keep down the wild grasses as much as possible. Grasses along fence rows and roadsides near the grain fields may be the source of a great deal of infection in the spring. Clean cultivation in the fullest sense is likely, therefore, to reduce the amount of scab somewhat. This would be particularly effective if all farmers in a community followed the same practice.

Epidemics of scab are likely to occur when weather conditions are favorable for its development, in spite of the precautions enumerated. As the organism which causes the disease is carried by the wind, cooperative effort over a large area would be necessary in order to reduce the amount by the methods described. The only hope of controlling the disease seems to be in the development of resistant varieties.

Unfortunately, Marquis, the most popular hard red spring wheat, is extremely susceptible to scab. Preston, Haynes bluestem, and some of the other hard red spring wheats which are not now grown extensively, are much more resistant than is Marquis. It is hoped that it will be possible eventually to obtain scab resistant wheats which have other desirable characters as well.

## SUMMARY

1. Scab of wheat has been known in Minnesota for more than twenty years. The disease appears to have become more prevalent with the general adoption of Marquis wheat, a variety which is very susceptible to scab.

2. The disease was first described in 1884 in England by Smith, who named it "wheat scab." Since that time it has been the subject of numerous investigations but there is yet much to be learned about the disease.

3. The disease is widespread in Europe, Australia, and North America. It is apparently more severe in North America than in Europe or Australia. It is most destructive in the corn belt of the United States, where it often does great damage.

4. Scab causes a head blight and a seedling blight of wheat. On the heads the disease becomes evident soon after the blooming period. Affected spikelets appear to have ripened prematurely, and under certain conditions, are covered with white or pinkish fungous mycelium. They are often cemented together with a pink or orange incrustation. Affected kernels are shriveled and discolored. The seedling blight in general can not be distinguished from that caused by other fungi. The young plants may be either stunted or killed.

5. The principal cause of wheat scab in Minnesota is probably *Gibberella saubinetii* (Mont.) Sacc. (*Fusarium graminearum*) Schwabe.

6. Infection may be brought about in several ways: namely, through infected seed, infested soil, debris, and corn stubble. Spores from these sources may be disseminated by wind, insects, or other carriers.

7. Over-wintering experiments demonstrated that mycelium and spores may live over winter in Minnesota if protected from the injurious effects of light.

8. The cardinal temperatures for the pathogene on artificial media are: 3 degrees, 25 to 27 degrees, and 33 degrees, C.

9. Spore germination is most rapid at temperatures near the optimum for the growth of the mycelium.

10. Normal wheat seed germinated between 5 and 33 degrees C., the best germination occurring at approximately 25 degrees.

11. When scabby seed were germinated at temperatures between 30 and 33 degrees C., the scab fungus grew so poorly that the seedlings in most cases escaped injury. The same was true when they were germinated at from 10 to 15 degrees C.

12. Field observations indicate that the disease develops most rapidly at temperatures near the optimum for the growth of the pathogene.

13. Various types of wheat, barley, and rye are susceptible. Oats are only slightly susceptible, but many grasses may be heavily infected.

14. By artificial inoculation and observations of natural infections the host range of the pathogene has been extended to many hosts widely separated taxonomically. The organism caused seedling blight of flax, clover, tomato, radish, pea, and cucumber; a stem rot of squash, bean, tomato, cucumber, pea, and sunflower; and rot of apples, carrots, and potato tubers. Living, uninjured leaves of tomato plants and both leaves and pods of bean plants were infected artificially, and the organism was reisolated from the attacked tissues. A root rot of bean, similar to the one found naturally on corn, also was obtained.

15. No entirely satisfactory control measures for wheat scab are known. Experiments showed that planting scabby untreated seed lowers the percentage of germination and introduces virulent cultures of the organism into soil in close proximity to the healthy seedlings, making them more liable to attack. Fanning, treatment of seed, and other sanitary measures, therefore, may be of some value in preventing seedling blight.

Crop rotation also seems to reduce the amount of disease. A survey of Minnesota in 1919 showed a much higher average percentage of scab on wheat grown after corn than on wheat after wheat, rye, or barley.

16. Observations and experiments have demonstrated wide differences in susceptibility of different varieties of wheat to scab. A resistant variety possessing other desirable agronomic characters, however, is not yet known.

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## LEGENDS FOR PLATES

Plate I. Scab on Kernels and Heads of Wheat Naturally Infected

Fig. A1 and A2. Equal numbers of scabby and healthy kernels.

Fig. B. Infected head of wheat showing small black perithecia as they appear late in the season.

Plate II. Wheat Scab Organism, *Gibberella saubinetii* (Mont.) Sacc. (*Fusarium graminearum* Schwabe)

Fig. 1. Conidiophores from which vegetative spores are formed.

Fig. 2. Vegetative spores in process of germination.

Fig. 3. Strands of vegetative mycelium.

Fig. 4. Mature perithecium of the ascus or sexual stage of the organism.

Fig. 5. Detail of perithecial wall.

Fig. 6. Group of asci from within the perithecium showing immature asci.

Fig. 7. Mature ascus with ascospores.

Fig. 8. Mature ascospores.

Plate III. Relation of Temperature to Growth of Wheat Scab Organism

Fig. A. Relation of temperature to growth of mycelium (five days after inoculation).

1. 5°C. (41°F.) 2. 10°C. (50°F.) 3. 15°C. (59°F.)
4. 20°C. (68°F.) 5. 25°C. (77°F.) 6. 30°C. (86°F.)

Note that above the optimum (25°C.) the character of growth is different from that at the optimum and below.

Fig. B. Relation of temperature to seedling blight of wheat

Seedlings of wheat are inoculated with wheat scab organism and kept at different temperatures. Seven days after inoculation. Tubes at the right at each temperature are checks. Note that the shoots as well as the roots are killed at temperatures favorable for the development of the organism (19-25°C.). At temperatures above and below, the roots and shoots developed normally altho the organism was present and growing.

Plate IV. Results of Artificial Inoculation of Wheat with Wheat Scab Organism

Plate V. Results of Artificially Inoculating Various Plants with Wheat Scab Organism

Fig. A1 and A2. Stem rot of bean. Arrow indicates point of inoculation in diseased pot. Note stem punctures in check pot below (Fig. A2).

Fig. B1 and B2. Seedling blight of clover, two weeks after inoculation. Check pot on right.

Fig. C1 and C2. Stem rot of tomato, four days after inoculation. Arrows indicate points of inoculation in diseased pot. Check pot on right.

Fig. D1 and D2. Stem rot of cucumber. Arrows indicate points of inoculation in diseased pot. Check pot on right.

Fig. E. Potato tuber several weeks after inoculation.

Plate VI. Stem Rots Due to Wheat Scab Organism

Fig. A. Pea. Check pot on right.

Fig. B. Sunflower. The first and seventh pots from the left contain check plants; the soil of the third pot was inoculated with *Fusarium lini.*

Fig. C. Squash

Pot. 1, (a) Leaf petiole inoculated with *Fusarium lini.*
(b) Leaf petiole inoculated with wheat scab organism.
(c) Leaf petiole inoculated with wheat scab organism.

Pot 2, Stem inoculation

Pot 3, Check.

Plate VII. Root Rots Due to Wheat Scab Organism

Fig. A. Dry root-rot of bean. Plants on right inoculated with *Fusarium martii phaseoli,* the bean root-rot organism. Plants in the middle inoculated with wheat scab organism. Plants on left, checks.

Fig. B. Root-rot of corn. Plants on left inoculated with wheat scab organism, those on right, checks.

Plate VIII. Root-Rot of Corn Due to Wheat Scab Organism

Pot. 1, Soil inoculated.

Pot. 2, Check.

Pot 3, Check.

Pot. 4, Soil inoculated.

Plate IX. Effect of Treatment with Formaldehyde upon Development of Wheat Seedlings

Pot A, Healthy seed.

Pot B, Scabby seed, treated.

Pot C, Scabby seed, untreated.

PLATE I

PLATE II

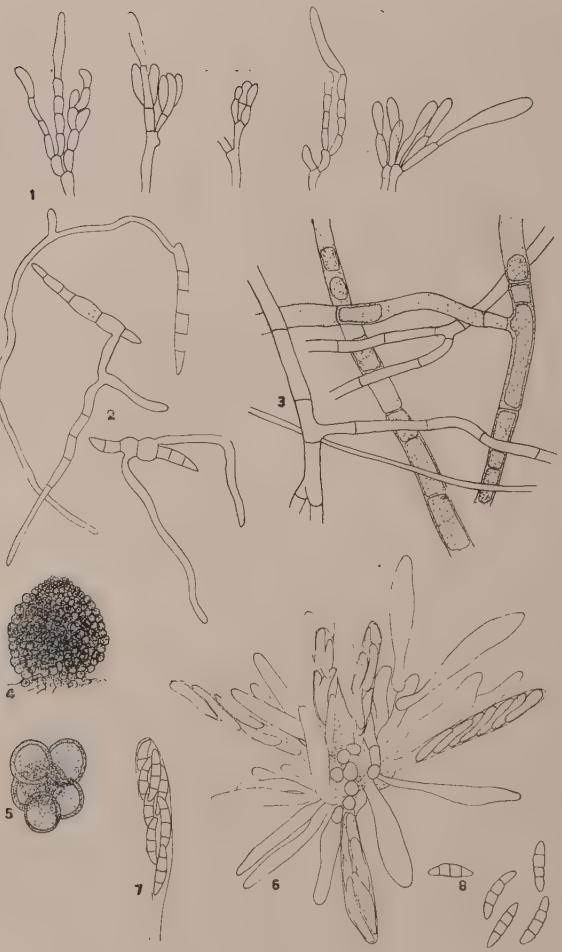
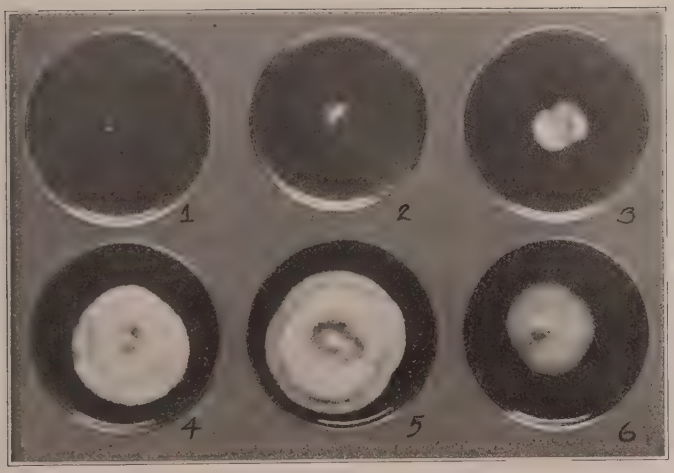


PLATE III

A

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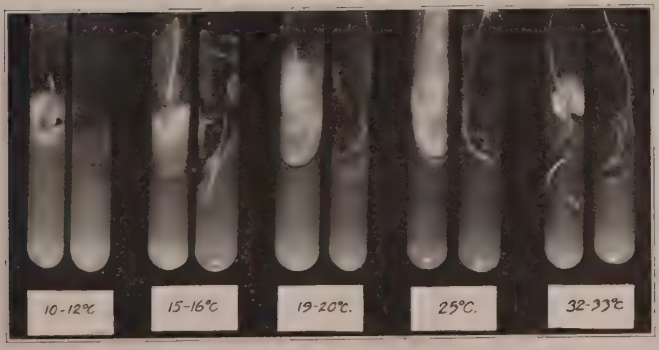


PLATE IV

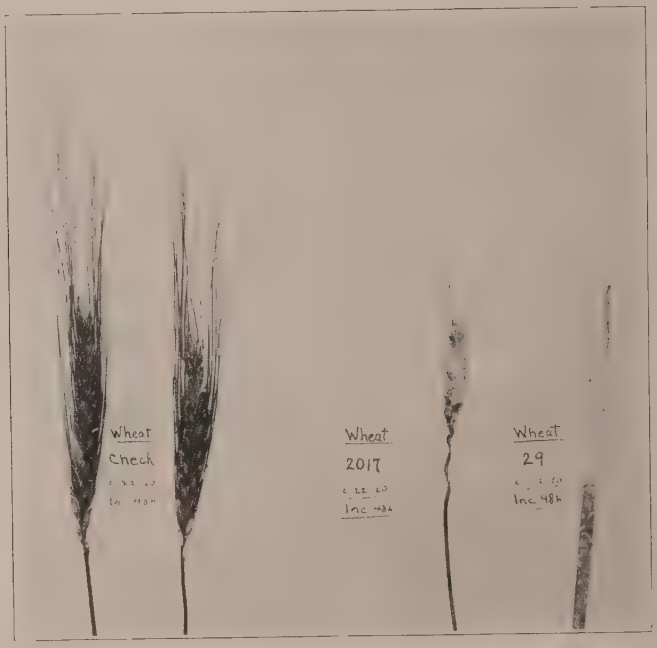


PLATE V

PLATE VI

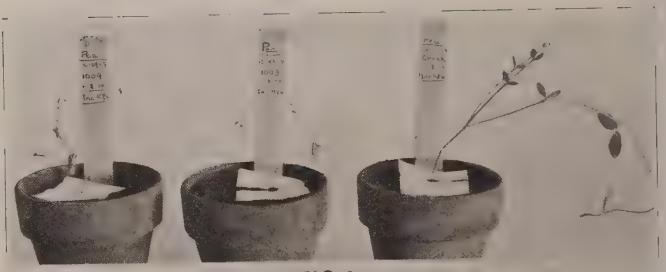


FIG A

FIG B

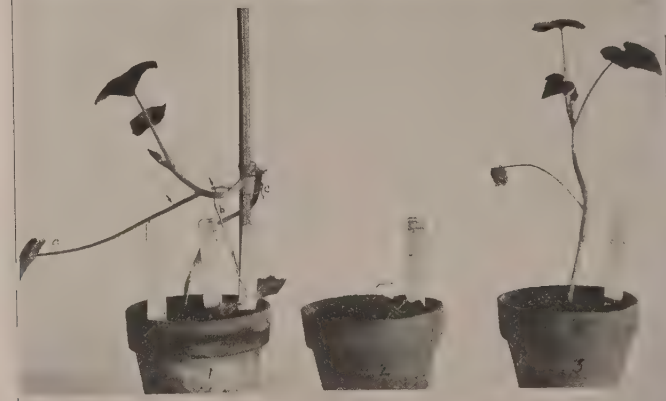


FIG C

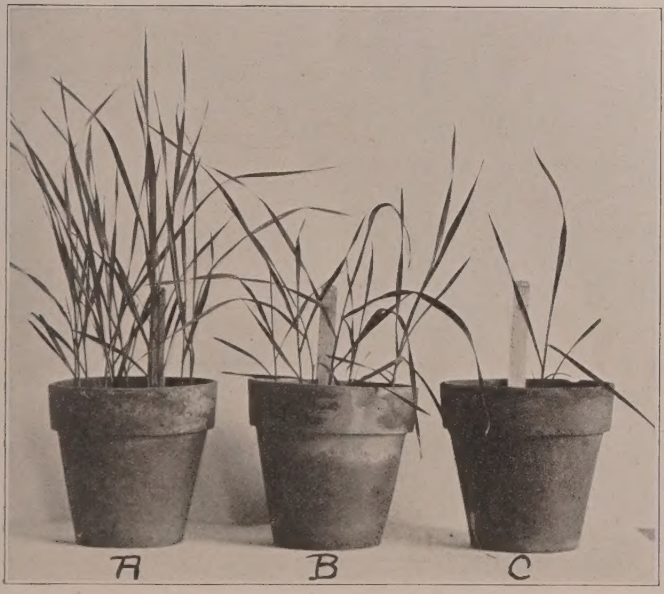
PLATE VII

A

B

PLATE VIII

PLATE IX



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